DETECTION OF PLANT STRESS THROUGH MULTISPECTRAL PHOTOGRAPHY

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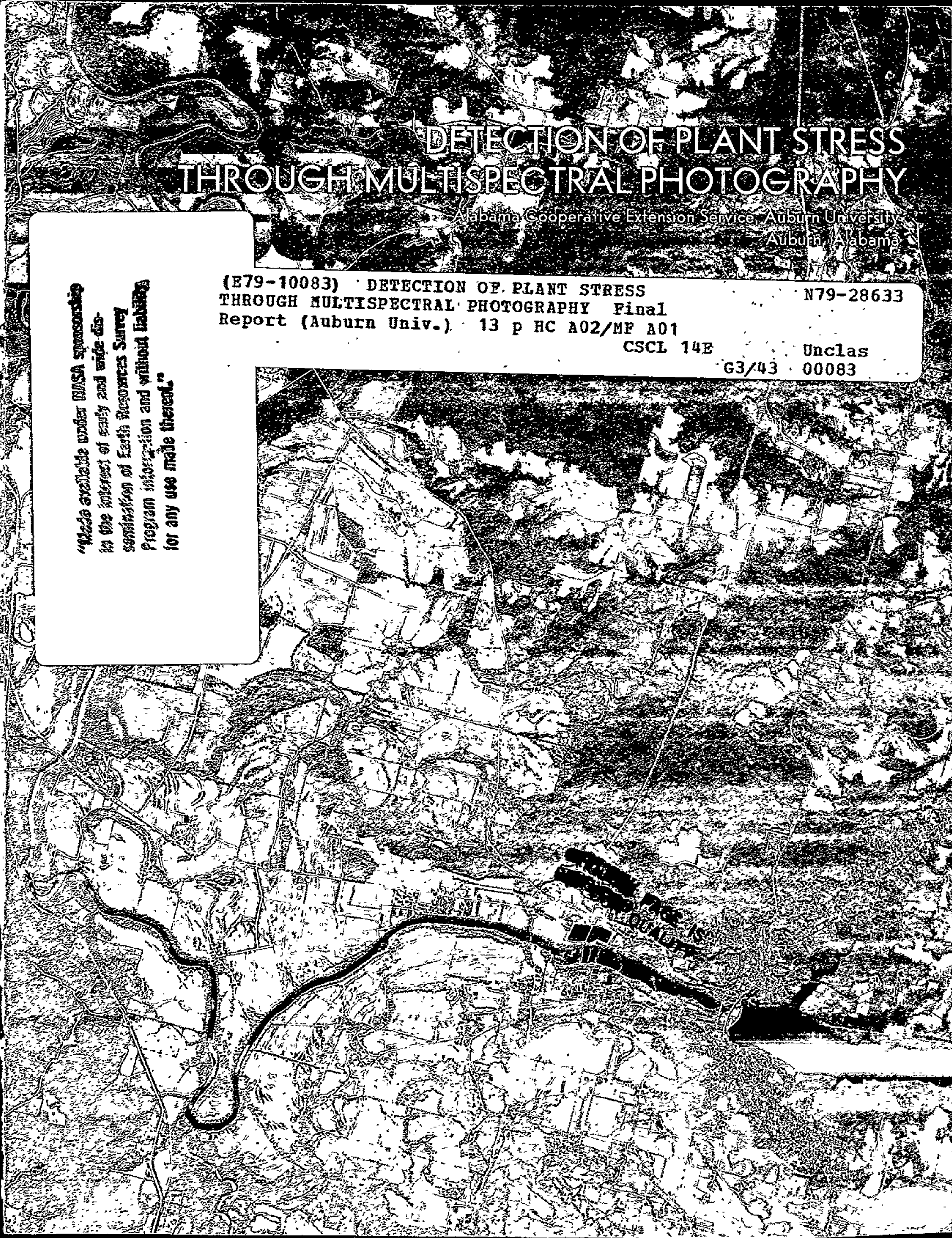

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PRODUCTION of sufficient food, feed, and fiber is the greatest challenge facing the American farmer today. To effectively and efficiently accomplish this task, producers must use every management skill and technique available to them. Efficient production requires the judicious use of liming materials, other fertilizers, and pesticides.

Major food, feed, and fiber crops grown in Alabama include soybeans, peanuts, corn, cotton, forages, small grains, vegetables, and fruits. All of these generally require lime, fertilizer, and pesticides to promote growth, quality, and protection from harmful pests.

Acid soils constitute the greatest single crop production problem throughout Alabama. Removal of this one limiting factor could more than double yields. Research results and demonstrations on farmer fields have shown that as the soil pH declines to 5.0, many crops show visible damage and begin to die (Figure 1). Furthermore, research at Auburn University and elsewhere has also shown that even before low pH injury is visible, yields may be significantly depressed. Growers and lime dealers need to become more aware of the detrimental effect of acid soils on crop yields and the necessity of providing an adequate supply of high quality crushed agricultural limestone and other liming materials for optimal yields.

Damage from plant diseases and parasitic nematodes costs Alabama crop producers approximately $65 million annually. Virtually every crop grown for commercial purposes or home use is adversely affected by plant parasitic nematodes (Figure 2) and diseases. Detection of these threatening pests, in order to control, contain or eradicate them, is important to every Alabama grower.

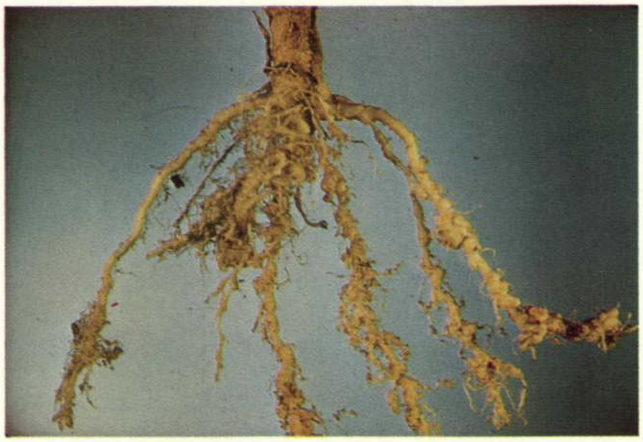
The potential of multispectral photography for detecting plant stress was described by Paludan (6) with specific reference to nematode and low soil pH problems on tomatoes in the Chandler Mountain area of Alabama. Others (1, 3, 8) have also suggested the possibility of using aerial photography to identify plant problems.

Soybeans on limed (bottom) and unlimed (top) soil.

Cotton on limed (right) and unlimed (left) soil.

Figure 1. Effect of low soil pH on growth of crops.

Normal cotton roots and nematode infested roots.



Nematode damage on tomato roots.

Figure 2. Nematode damage on cotton and tomatoes.

A joint demonstration program was begun between the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Alabama, and the Alabama Cooperative Extension Service, Auburn University, to determine whether multispectral photography could reveal plant stress caused by low soil pH and parasitic nematodes in Alabama crops.

The study began in 1971 with a small demonstration with tomatoes on Chandler Mountain in St. Clair County, Alabama. The two agencies began working under a formal contract (NAS8-29856) in 1973. Initially three important agricultural crops—cotton, peanuts, and tomatoes—were selected for study. Soybeans and forage grasses were included in later demonstrations.

OBJECTIVES

This demonstration project was designed to determine whether multispectral photography can be used to detect stress on selected crops. Specific objectives of this study were:

1. To demonstrate how effectively aerial multispectral photography by conventional aircraft, high altitude aircraft (RB-57, etc.) polar satellite, or orbiting space stations can be used to detect plant stress caused by low soil pH and plant parasitic nematodes.

2. To demonstrate optimal crop age and/or season when multispectral detection of plant and soil problems is most effective.

3. To develop an educational program using multispectral photographs to show the extent of plant and soil problems on selected crops.

4. To develop aids (manuals, slide sets, etc.) for training county Extension personnel to use multispectral photography and equipment at the county level.

METHODS

Demonstrations

The project was not approved until after test crops had already been planted by individual growers using varying cultural practices. Therefore, no demonstration plots with selected practices for cotton, peanuts, and tomatoes could be established during the 1973 crop year. A decision was made to use existing known problem areas and smaller demonstrations to obtain preliminary data, rather than delay activities until the next crop year.

Sites for overflights were selected in Elmore, Autauga, Limestone and St. Clair counties. Flights were delayed until late September and mid-October by low light intensity and other weather conditions.

Ground truth data were collected on each selected plot except Chandler Mountain in St. Clair County, on the dates of overflights. These included a concise description of physical conditions in the target area at the time of the overflight. Information was recorded on the target plant; time of day; location of plot; gen-

eral soil type; weather conditions; soil pH; nematode damage; special insect, disease or weed problems; any special identifying objects such as trees or shrubs; and rough dimensions of the field and plot.

Plots were marked with 20- x 20-foot pieces of white plastic with overlays of black plastic placed to indicate magnetic north. The sites were also marked on county maps to further help flight personnel locate them.

Multispectral aerial photographs were taken of selected sites at altitudes of 3,000 and 12,000 feet in Elmore, Autauga and St. Clair counties on September 20; at 3,000 feet on September 21, and 12,000 feet on October 19, 1973 in Madison and Limestone counties. These photographs were studied and evaluated in an attempt to correlate overflight information with ground truth data.

Additional demonstration sites were selected for 1974 tests. Each site was visited, ground truth data obtained, and soil samples taken to determine the fertility, pH and nematode status for treated and untreated plots. Check plots of approximately 1-acre (100′ x 400′) were left untreated.

Because long, narrow objects are easier to detect in aerial photographs, white plastic markers measuring 12′ x 50′ were used. County maps and aerial photographs showing the location of each test site were obtained, marked, and made available to Marshall Space Flight Center for use by the flight crew.

Overflights of demonstration sites were made at altitudes of 3,000 and 12,000 feet beginning in the Dothan area on July 10; the Chandler Mountain and Blount County areas on July 31; the North Alabama area on August 19 and 20; and the West Alabama area on September 13. A high altitude flight (60,000 feet) was made from the Lyndon B. Johnson Space Center over Central Alabama on October 1, 1974, to determine whether plant and soil problems could be detected at higher altitudes.

Ground truth data from each site were obtained during the growing season for comparison with photographs from overflights.

Because of restricted funds for overflights, demonstrations for the 1975 crop year were concentrated in North Alabama, closer to Marshall Space Flight Center. Before the demonstration sites were selected, county Extension workers reviewed soil test reports in an effort to pinpoint low soil pH and nematode problems on the main target crops of cotton, soybeans, and forage grasses.

Sites were visited, soil samples taken and analyzed, and other information recorded. Soil test results were used as a guide in selecting untreated check plots of approximately one acre. Other sites in the demonstration areas were fertilized, limed and/or treated for nematodes in accordance with soil test recommendations.

Each demonstration site was located on county maps, and aerial photographs of each test site were provided. These were used by flight personnel in locating the target areas.

Throughout the growing season, demonstration sites were visited and ground truth data obtained on crop growth, presence of special weeds, insects, diseases, or any other problem that might affect interpretation of aerial photographs. Slides and photographs were also made of untreated and treated areas.

Overflights were made at altitudes of 3,000 and 12,000 feet on August 13 and 24, September 2 and 3, and October 3, 1975. Overflights were also made of forage grass and other crops on selected test sites on January 15, 1976, to determine the effectiveness of multispectral photography in detecting soil problems during winter months.

Aerial photographs were compared with test site photographs and with ground truth data obtained during the growing season.

Aerial Photography

Aerial photography has been used for studying conditions of vegetation for many years. One of the first of such studies, conducted by Colwell (2) beginning in 1952, showed that aerial photographs could be used to determine cer-

tain diseases in some cereal crops. A number of studies have been conducted since that time and their results reported in the literature. Most of these studies utilize conventional aerial photography and no attempt will be made here to review the results of these many experiments.

In this project, most of the aerial photography used was multispectral, but at high altitudes, color infrared photographs were obtained with a conventional aerial camera.

Multispectral photography consists of recording two or more images simultaneously in different parts of the electromagnetic spectrum. Four-band multispectral photography was used in this project, in which that part of the electromagnetic spectrum from the ultraviolet into the near infrared is divided into four bands. These four bands are defined as follows:

1. blue 400-800 nanometer wavelength
2. green 480-590 nanometer wavelength
3. red 590-700 nanometer wavelength
4. infrared 730-900 nanometer wavelength

The aerial camera used is shown in Figure 3. It is equipped with four lenses having focal lengths of 150 mm, which are aligned to view the same scene. The camera is equipped with a focal plane shutter which exposes the film to record images simultaneously in the four different bands. Each lens is equipped with filters

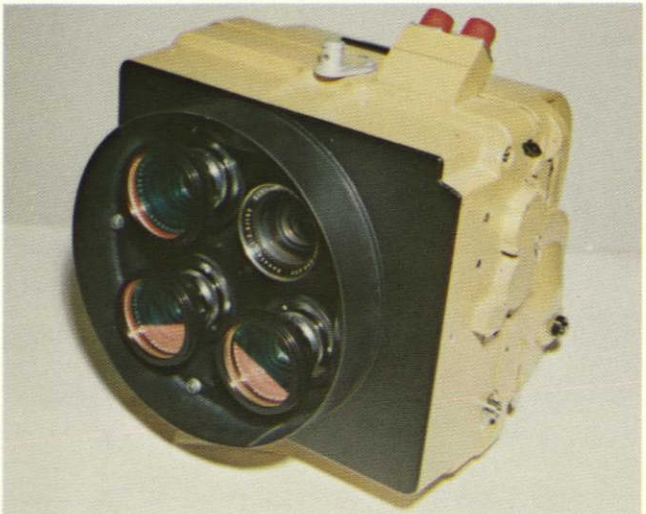


Figure 3. Four-band multispectral aerial camera.

so as to record the energy in the selected band only. The pass bands of these filters are shown in Figure 4. The images are recorded on black and white aerial infrared film (Kodak Infrared Aerographic Film 2424)[1]. The characteristics of this film are given in Eastman Kodak Publication M-29, Kodak Data for Aerial Photography (5).

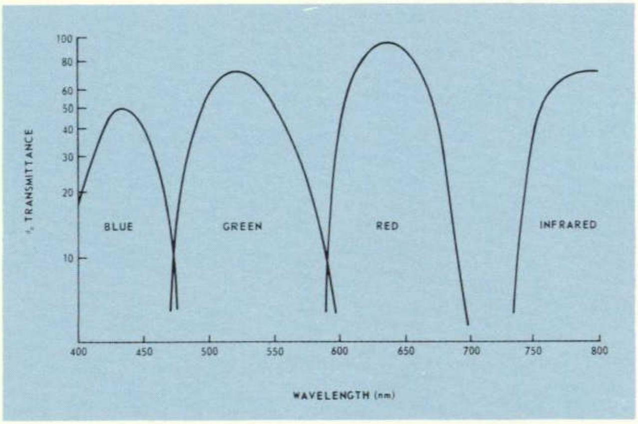


Figure 4. Transmittance of filters.

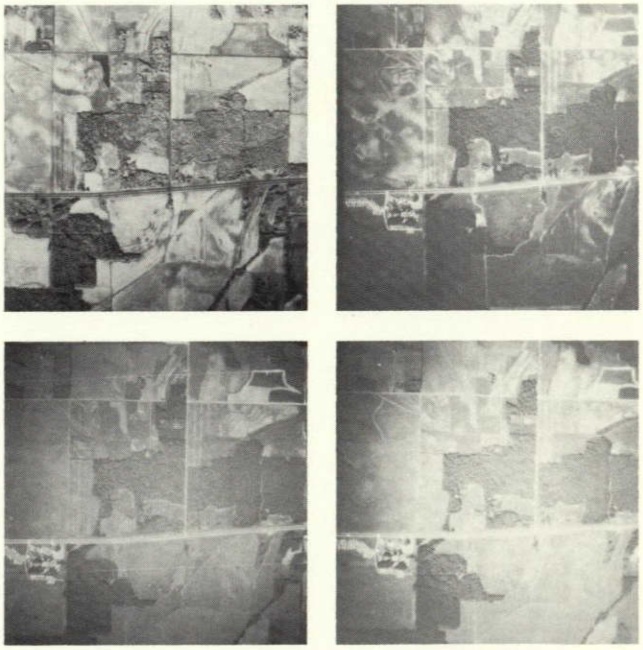


Figure 5. Images obtained by multispectral photography. Beginning at lower left and proceeding counter clockwise, the spectral bands are blue, green, red, and infrared.

The format consists of four individual images, each 9.25 cm square on a standard 22.9 cm square aerial photography format. A typical image is illustrated in Figure 5.

[1] Trade names are used for convenience only and are not to be considered as an endorsement.

In order to obtain the maximum benefits of multispectral photography, a special color additive viewer, shown in Figure 6, must be used. The viewer consists of four separate projections which simultaneously project and superimpose the four individual images on a viewing screen. Adjustments are provided so that the images can be properly registered with each other. Blue, green, or red filters may be inserted in each projector light path. If the blue, green, and red, black and white images are projected on the screen with no filters, an image will be obtained

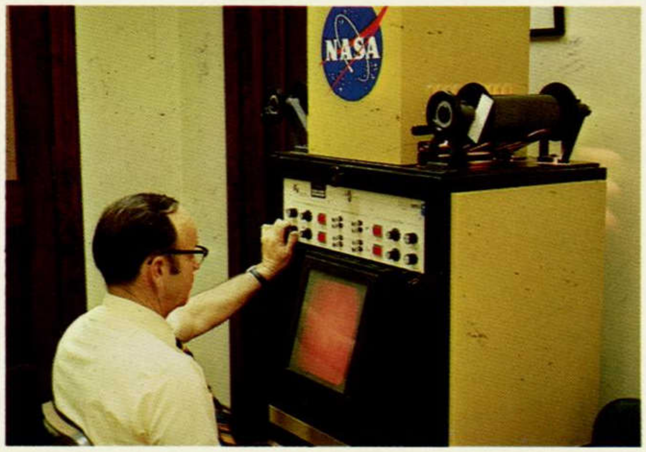


Figure 6. Color additive viewer.

similar to a black and white aerial panchromatic photograph. If the green, red, and infrared bands are projected on the screen without using the filters, an image will be obtained which is similar to aerial infrared photography obtained using black and white infrared film and a minus blue filter. Reconstructed conventional color can be obtained by projecting the blue band through a blue filter, the green band through a green filter, and the red band through a red filter. In this image the colors in the images will appear as they do when the scene is viewed by the human eye. Color infrared images can be obtained by projecting the green band through a blue filter, the red band through a green filter, and the infrared band through a red filter. This image is similar to the image obtained using color infrared film, and in this image vegetation will appear as varying shades of red.

One of the most important advantages of multispectral photography is that the bands may be selected and projected on the viewing screen through selected filters to create many different false color images. The color of these images may bear no relation to the colors in the actual scene, but sometimes detail can be obtained that is not apparent in ordinary aerial photography. One of the most useful images for studying crops is obtained by projecting the red band through a red filter and the infrared band through a green filter. In this image healthy vegetation appears green while bare ground and dead or dying vegetation appears as shades of red. Figure 7 is an image of this type.

For additional information on the development and characteristics of four-band multispectral photography, the reader is referred to Yost and Winderoth (9). The application of multispectral photography to agriculture and forestry is also described by Yost and Winderoth (10). The system of cameras and views used in this project is described more completely by Ross (7).

The multispectral photographs used in this project were obtained by the George C. Marshall Space Flight Center, National Aero-

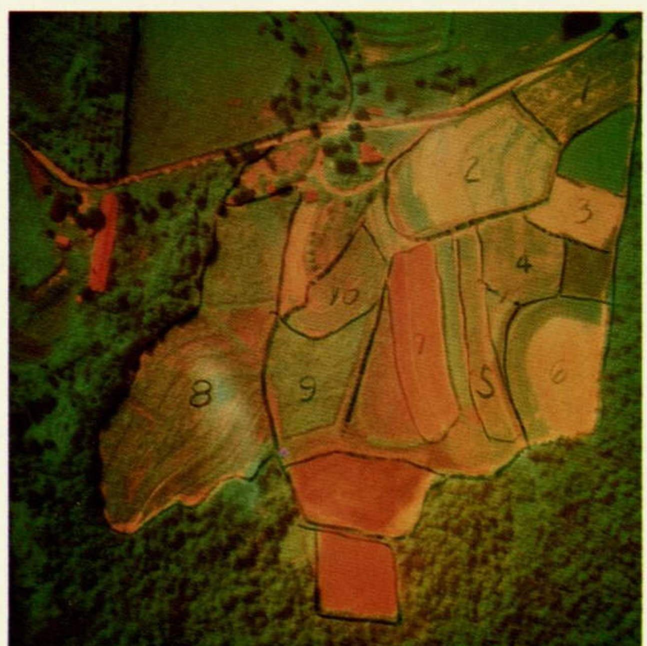


Figure 7. False color image created by projecting the red band through a red filter and the infrared through a green filter. Healthy vegetation appears green, while dead or dying vegetation and bare ground appear in shades of red.

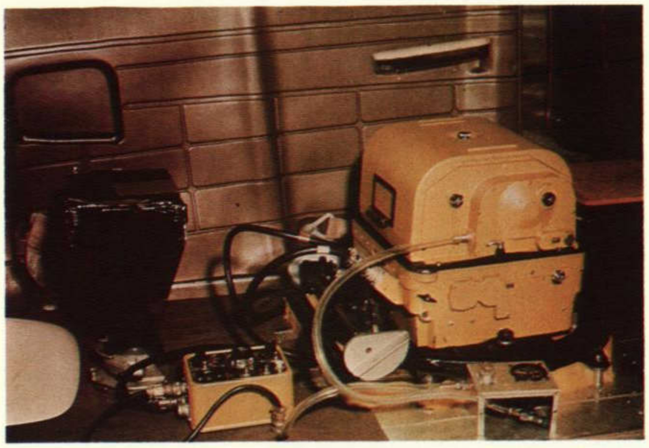


Figure 8. Four-band multispectral aerial camera mounted in aircraft.

nautics and Space Administration, using a four-band camera mounted in a C-45 aircraft (Figure 8). These images were obtained at altitudes of 3,000 feet and 12,000 feet. The high altitude photographs were obtained by the Lyndon B. Johnson Space Center, National Aeronautics and Space Administration, using an RC-8 aerial camera mounted in the RB57F aircraft at an altitude of 60,000 feet.

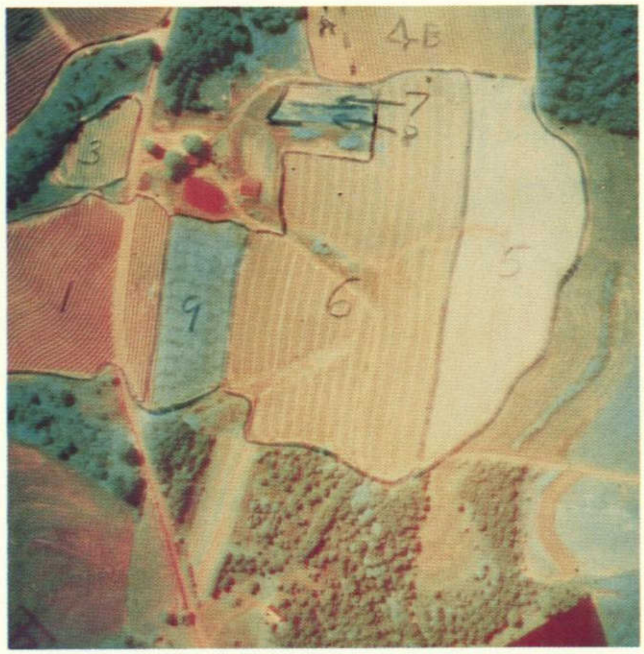
Interpretation of Results

A Model 600 Mini-Addcol Color Additive Viewer was used to study aerial photographs made each year during overflights of the demonstration sites. The photographs were studied under the various wavelengths and filter combinations described above. They were also compared with photographs made at the test sites during the growing season.

Ground truth data collected at the demonstration sites at the time the tests were established, plus data on each target crop, were used to interpret aerial photographs. The combination of multispectral photography and ground truth data was very useful in interpreting results.

RESULTS

Multispectral aerial photographs of tomatoes and other crops taken prior to the formal initiation of this project in St. Clair County (Figure 9), showed that multispectral photography could be used to detect crop growth differences. Note that in the top photograph differences in growth after broadcast treatments of liquid nemagon for nematodes on tomatoes (fields 1, 2, and 6) are much more pronounced than in fields 3 and 5 where the nematode treatments consisted of nemagon granules applied in the fertilizer. Both ground truth data and aerial photographs showed even greater differences



False color image of treated test site. Fields 1, 2, 3, 4B, 5, and 6 are treated tomato fields. Field 7 is okra. Field 8 and 9 are beans. Field 4A is an untreated tomato field.

False color image of treated and untreated fields. Fields 1, 2, and 4 are untreated tomatoes. Fields 3 and 5 are untreated beans, 6 is pasture. Field 7 is on adjoining farm, 7A is idle, 7B is treated tomatoes.

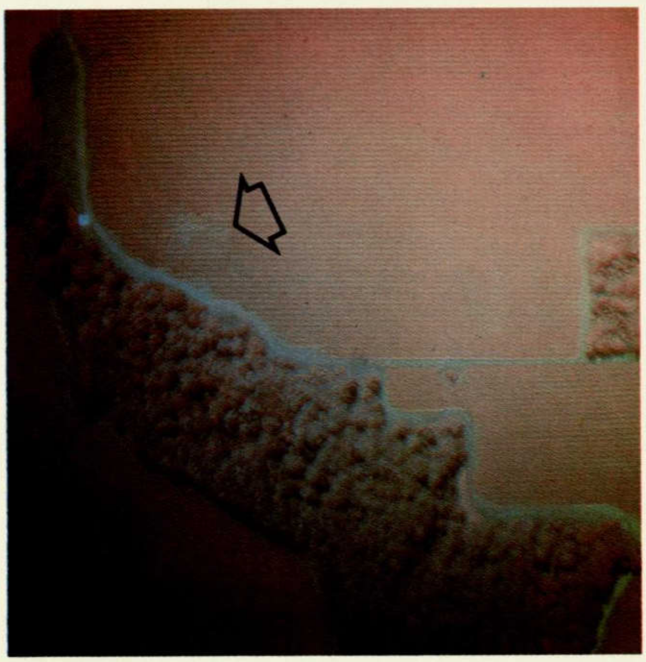
Figure 9.

between plots which received no nematode treatment (4-A) and those which received the recommended broadcast treatment (4-B) for nematode control on tomatoes. Similar differences were noticed on treated and untreated okra (field 7).

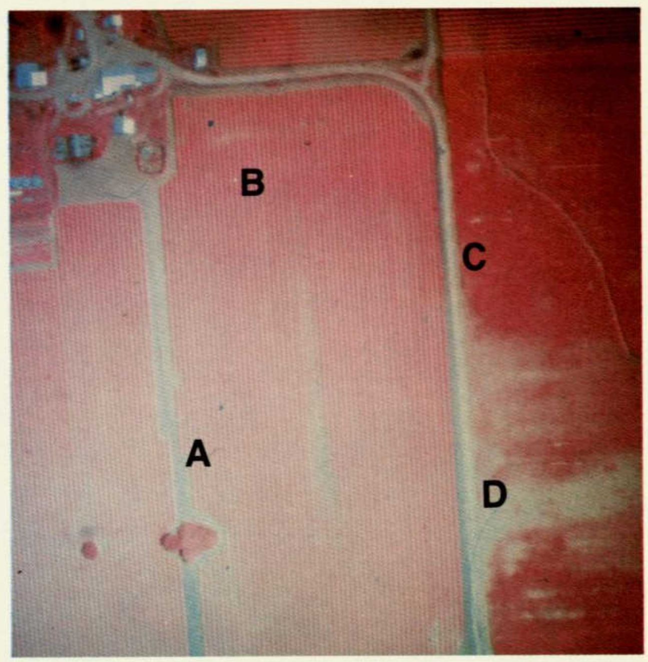
Striking differences on another farm (Figure 9, lower photograph) were noted between treated and nontreated tomatoes. In field 1 no lime or nematode treatments were used. Note how these problem areas (lighter color) can be detected. Compare this with field 7-B where both lime and nematicides were applied.

No-lime plots as small as 25 x 25 feet could be detected in a cotton field in Madison County from aerial photographs made from an altitude of 3,000 feet (Figure 10, left photograph). Little or no cotton was present on the no-lime plots at the time the photographs were made and no cotton was harvested from these plots. Adjacent plots which received lime at rates recommended by soil tests yielded 750 pounds of lint cotton per acre. At the 1973 price of $47\frac{1}{2}$ cents per pound, this resulted in a gross income of $356 per acre in favor of the limed plots. Detection of plant stress due to problems such as low soil pH is important to the economy of Alabama cotton growers.

Overflight photographs made of demonstration sites in Limestone County at 3,000 feet on September 21, 1973, and 12,000 feet on October 19, 1973, revealed outstanding differences between limed and unlimed areas in cotton and soybean fields. Both cotton and soybean fields on one farm had been limed in accordance with soil test recommendations. Adjoining fields rented by the farmer to grow cotton and soybeans were so heavily fertilized that soil tests revealed high levels of phosphorus and potassium. These fields were not limed, and the soil pH was 4.5. Soil magnesium was also low, and the soil was so acid that both cotton and soybeans failed to grow, resulting in a complete crop failure. This condition was easily detected from overflight photographs.



Color infrared image of cotton test site. Field had recommended application of lime, except for check plot (see arrow) which had no lime applied.



Color infrared image of cotton and soybean test site. A—Cotton with lime applied, B—Cotton with double application of lime, C—Soybeans with lime applied, D—Check plot with no lime.

Figure 10.

In order to better compare the aerial photographs with ground truth data, a demonstration using lime and no-lime plots on soybeans was established on a low soil pH (4.3) field in the Greenbrier Community of Limestone County.

Photographs from the overflights showed the no-lime plot very distinctly (Figure 10, area D in right photograph) including one edge of the check plot where a small amount of lime blew onto the plot during application on a windy day. Note also the uneven distribution of lime along the field road on either side of the check plot. Compare these areas with area C where the distribution of lime was uniform. An adjoining field of cotton where the soil pH was 4.5 the previous year was limed in accordance with soil test recommendations prior to planting the cotton (Figure 10, right photograph, area A). A double application of lime was applied on one end of this cotton field (area B). Compare this area with area A where a single application of lime was made.

The unlimed (pH 4.3) check plot (Figure 10, area D in right photograph), produced only $2\frac{1}{2}$ bushels of soybeans per acre and the limed (pH 6.5) area (C) produced 38 bushes per acre in 1974. At $6 per bushel, additional income was $213 per acre from the limed plot. In 1975 the yield of soybeans from the unlimed plot was 0 bushels per acre while the limed plot yield was 32 bushels per acre.

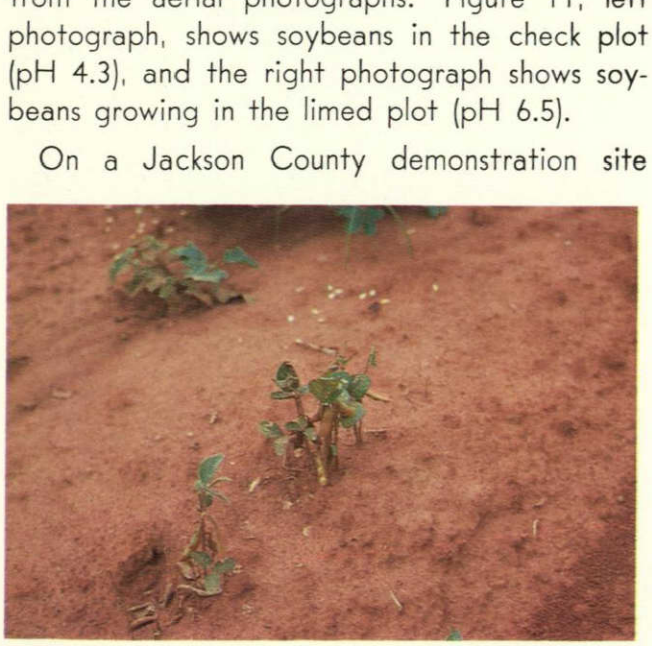
Ground truth data collected from the soybean demonstration site supported data obtained from the aerial photographs. Figure 11, left photograph, shows soybeans in the check plot (pH 4.3), and the right photograph shows soybeans growing in the limed plot (pH 6.5).

On a Jackson County demonstration site planted to cotton in 1974, the yield of seed cotton from the check plot (unlimed) was 386 pounds per acre, and that from the limed plot was 2748 pounds per acre. At 20 cents per pound for seed cotton, this would mean $192 gross income per acre in favor of the limed plot.

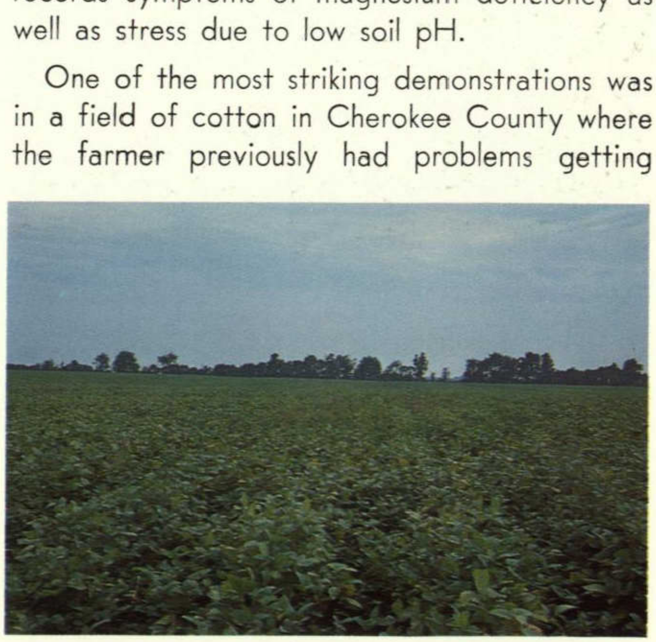
In addition to the demonstrations on soybeans, cotton and tomatoes in North Alabama, limed and unlimed plots were established in Houston County to determine the effectiveness of aerial photographs in detecting low soil pH on peanuts. Differences in limed and unlimed areas can be easily detected (Figure 12). Area A shows the limed plots and area B shows the unlimed plots. No yield data were obtained on this demonstration because the primary objective was to determine whether aerial photography could be used to detect soil problems in peanuts.

Photographs in Figure 13 show a somewhat different soil stress problem on tomatoes. The color infrared photograph at top shows plant stress due to both low soil pH and low magnesium. Calcitic limestone was used to correct low soil pH on the limed area, but magnesium deficiency was prevalent in spots throughout the field, as shown in the light area. The lower color photograph, taken at the test site, records symptoms of magnesium deficiency as well as stress due to low soil pH.

One of the most striking demonstrations was in a field of cotton in Cherokee County where the farmer previously had problems getting



Soybeans growing in unlimed plot (soil pH 4.3).



Soybeans growing in limed plot (soil pH corrected to 6.5).

Figure 11.

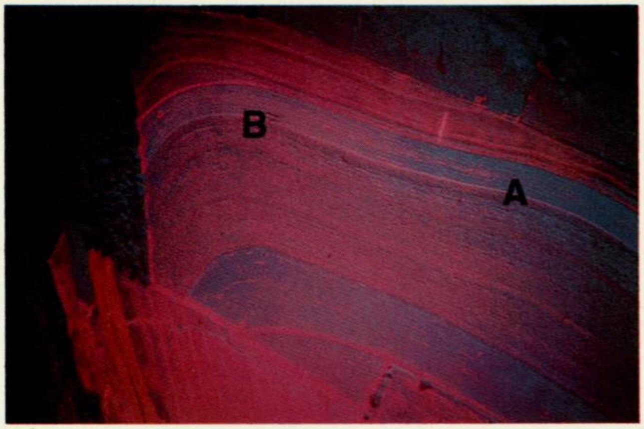


Figure 12. False color image of peanut test site. A—Lime applied, B—No lime.

optimal yields. Limed and unlimed plots were established. Approximately 1 acre with a pH of 4.6 was left as an unlimed check plot (Figure 14). In the photograph at left, taken of the test site at an altitude of 3000 feet, the limed plot (A) and the unlimed plot (B) can be detected. Even more striking are differences in the limed (A) and unlimed plots (B) in the photograph at right taken at the test site in June, 1975.

Larger areas of the demonstration site are shown in Figure 15. The limed plot is in the left photograph, and the unlimed plot is shown in the photograph at right. Compare this with Figure 14.

Yield of seed cotton was 196 pounds per acre on the unlimed plot and 1674 pounds per acre on the limed plot. At 50 cents per pound lint cotton, the difference in crop value per acre was $278 in favor of the limed plot.

One objective of this study was to determine whether aerial multispectral photographs taken from both conventional and high altitude aircraft could be used to detect plant stress. Photographs taken at low and high altitudes (Figures 16, 17, and 18) show cotton fields in Autauga County which were limed according to soil test recommendations to correct the soil pH. No nematicide was applied, however, and the cotton was showing stress from plant parasitic nematodes.

False color images in Figures 16 and 17 show that plant stress caused by plant parasitic nematodes can be detected from multispectral photographs made at 3000 feet (Figure 16, top and Figure 17) and 12,000 feet (Figure16,bottom). Lighter colors show the damaged areas.

The same demonstration site shown in Figure 16 is shown in a color infrared photograph made at an altitude of 60,000 feet on October 1, 1974 (Figure 18). Even at this late stage of growth, stress on the cotton from plant parasitic nematodes can be detected.

Although all objectives of this study were not achieved, comparison of ground truth data with

Color infrared photograph showing tomato plant stress due to low soil pH and magnesium deficiency. Red indicates healthy plants. Light color shows plant stress.

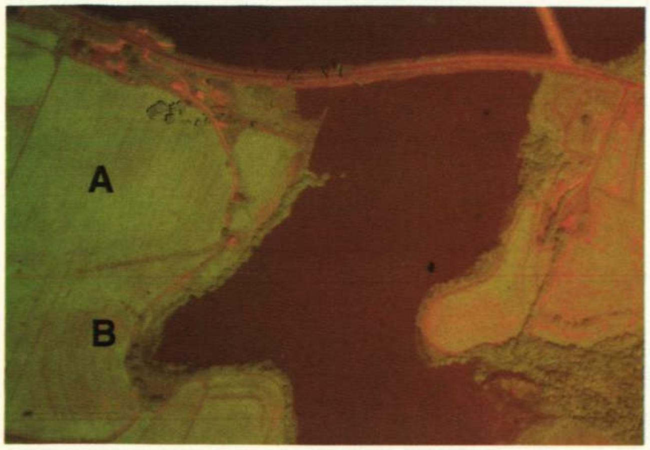
Tomatoes showing magnesium deficiency and stress due to low soil pH.

Figure 13.

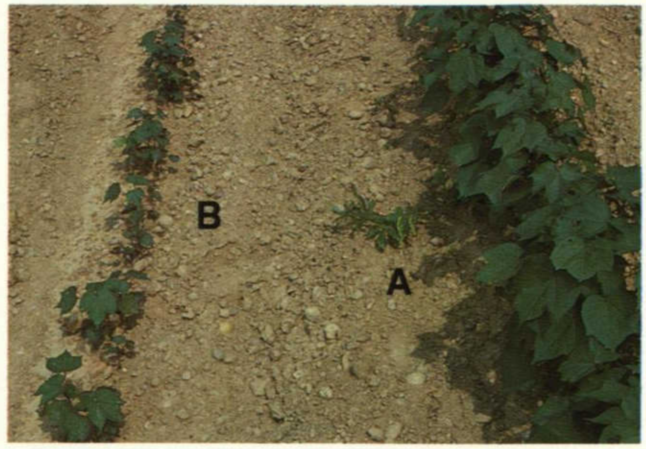
multispectral photographs led to the following specific conclusions:

1. Plant stress due to low soil pH and plant parasitic nematodes can be detected through multispectral photography.

2. When multispectral photography is used



False color image showing plant stress on cotton due to low soil pH. A—Limed plot. B—Check plot (no lime).



Photograph made at demonstration site showing effects of low soil pH on growth of cotton. A—Limed plot. B—Check plot (no lime).

Figure 14.

Limed plot. Agricultural limestone applied in accordance with soil test recommendations.

Check plot. No lime applied.

Figure 15. Photographs made at demonstration site on June, 1975, showing effects of low soil pH (no lime applied) and lime on growth of cotton.

alone, as in this study, plant stress caused by low soil pH cannot be distinguished from stress caused by plant parasitic nematodes. Stress in a given area may be due to only one of these conditions.

3. Plant stress can be detected in multispectral photographs taken from altitudes of 3,000, 12,000, and 60,000 feet. As expected, more details show up on lower altitude photographs.

4. Landsats photographs cannot be used to detect plant stress caused by low soil pH and plant parasitic nematodes because the resolution is not sufficient for detecting such small areas.

5. The latter part of the growing season is the best time to use multispectral photography for detecting plant stress.

6. Teaching is more effective when multispectral photographs are used along with ground truth data. Farmers, television viewers, and others have shown considerably more interest in photographs from overflights, where entire problem areas are shown, than in photographs of small areas taken at demonstration sites.

7. Multispectral photography can be used not only to detect plant stress, but has potential uses for:

a. Crop condition surveys including tree decline.

b. Disease detection.

c. Crop acreage determination.

d. Crop type determination.

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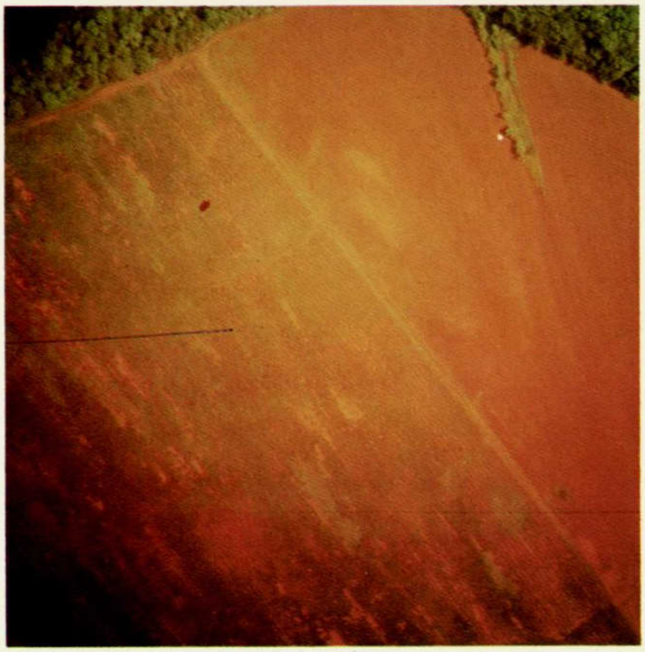
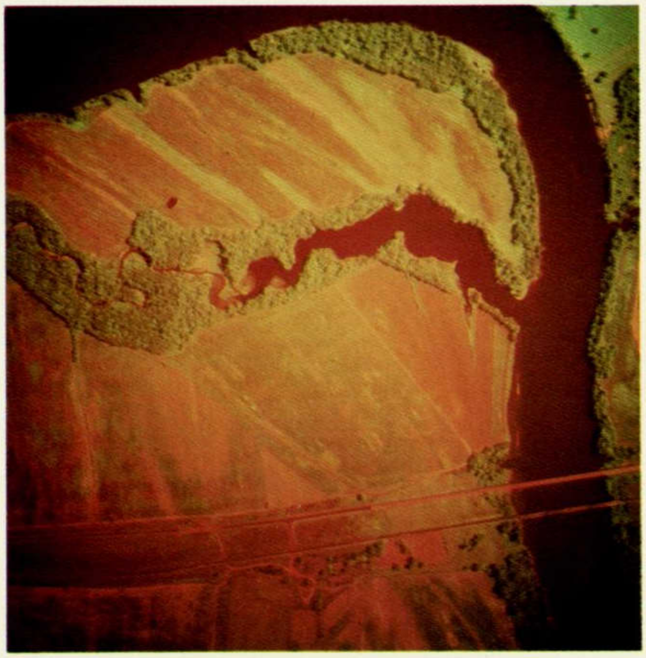


Photograph taken at 3000 feet altitude.



Photograph taken at 12,000 feet altitude. Lighter color shows damage.

Figure 16. False color image showing plant stress on cotton due to nematode damage.

Figure 17. False color image showing plant stress on cotton due to nematode damage. Lighter color shows damaged areas.

Figure 18. Color infrared photograph from 60,000-foot altitude taken on October 1, 1974 showing nematode damage to cotton in Autauga County on McQueen Smith Farms. Red shows healthy plants and light color shows stress caused by nematode damage.

The Alabama Cooperative Extension Service

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